STRATEGY RESEARCH PROJECT

CENTER OF GRAVITY ANALYSIS: PREPARING FOR INTELLIGENT AGENTS

BY

LIEUTENANT COLONEL MICHAEL BOWMAN
United States Army

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U.S. ARMY WAR COLLEGE, CARLISLE BARRACKS, PA 17013-5050

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LIEUTENANT COLONEL MICHAEL BOWMAN
Department of the Army

Professor Antonio M. Lopez Jr., PhD
Project Advisor

U.S. Army War College
CARLISLE BARRACKS, PENNSYLVANIA 17013

ABSTRACT

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The center of gravity is defined as the foundation of capability – what Clausewitz called the "hub of all power and movement, on which everything depends ... the point at which all our energies should be directed." This Strategic Research Project uses knowledge engineering and artificial intelligence techniques to identify and describe the background knowledge, concepts, information, and scenarios that would be required to create intelligent agents that would conduct center of gravity analysis. The paper explores the possibility of intelligent agents being used by strategic decision makers to assist in the determination of the center of gravity for a force. If this can be done, it will be a significant step in achieving information superiority and will have a profound impact on joint operational capabilities.

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"Discussion without definition is impossible."
— Sir Edward Grey, Great Britain's Foreign Minister World War I

War, its deterrence, conduct and termination is arguably the most complex of human endeavors. A technical accomplishment like sending a man to the moon may be recognized as a great achievement, but it involved for the most part, the control of known and quantifiable laws of physics. Military operations, ranging from the development of individual soldier skills, to the maneuvering of a theater army, the use of theater engagement plans, or the posturing of strategic nuclear forces, are exceedingly complex tasks governed by few quantifiable rules, and a distinct set of concepts and relationships. Military strength and readiness are among the key elements of national power used by national leaders to achieve strategic objectives. Military and political leaders use a lifetime of experience, education and practice to hone their problem solving and decision making skills in this environment. The human brain has an enormous capacity to collect information, evaluate situations, compare options and reach conclusions. In the most complex and critical decision making environments the human brain still, by far, out performs computers. Given the importance of these decisions and the time constraints under which they are often made however, the usefulness of technologies such as Artificial Intelligence (AI) are being investigated as tools to assist human decision makers.

In order for AI to become truly useful in high-level military applications, it is necessary to identify, document, and integrate into automated systems the human knowledge that senior military professionals use to solve problems. The skeletal structure for this expert knowledge is provided through the development of an ontology. An ontology defines the terms and relationships that are necessary to solve problems in a given domain. This paper first presents brief overviews on the levels of war and on ontology development. It then describes the ontology development for a tactical course of action critiquing agent done as part of the Defense Advanced Research Project Agency (DARPA) High Performance Knowledge Bases (HPKB) program. Course of action development is done at each level of war, but this intelligent agent was developed to support tactical operations. The paper next describes the expansion and extension of the course of action ontology to represent the military concept of center of gravity used at the strategic and operational levels of war. This work is a part of the DARPA Rapid Knowledge Formation (RKF) program being investigated by the George Mason University (GMU) Learning Agent Laboratory (LALAB) and the United States Army War College (USAWC). The resulting expanded military ontology will provide a starting point for the eventual development of intelligent agents that assist in strategic center of gravity determination.

THE LEVELS OF WAR

Three authors frequently quoted in lectures at the USAWC are Sun Tzu[1], Carl von Clausewitz[2], and Baron Antoine-Henri Jomini[3]. Their individual works though written in antiquity have been translated and published in the 20th Century because the concepts therein are deemed to be as valuable to military leaders today as when they were first described.

While the basic nature of war is constant, the means and methods of combat have evolved through time. Military operations of tomorrow will not be conducted in the same way they are today, and today's operations employ means and methods that are radically different than those of the past. However, one aspect of military operations that has remained relatively constant is the view that they occur at three different levels each with its own means, methods, and ends. These levels are tactical, operational, and strategic[4]. The tactical level is the lowest level of war. Its focus is the military application of unit combat power through the use of fire and maneuver that are basic actions for the execution of battles and engagements. Engagements are combat actions of a few hours or less duration fought at division level and below. Battles consist of a series of related engagements, last longer, involve larger forces and produce decisions that affect subsequent, higher level operations. Actions at the operational level imply a broader dimension of time and space – when, where, and under what conditions to engage or refuse to engage the enemy in battle. In this regard, Tzu[5] stated, "Invincibility lies in the defense; the possibility of victory in the attack. One defends when his strength is inadequate; he attacks when it is abundant." The operational level of war uses campaigns and major operations to attain strategic objectives. Strategic objectives are defined by national political objectives; war is after all a political action of last resort. Thus the strategic level, the highest of the three levels, can be thought of as the art of winning a war; the operational level can be thought of as the art of winning a campaign; and the tactical level can be thought of as the art of winning a battle.

The three levels of war encompass the entire range of military operations and military operations other than war. The three levels are related and supportive of one another with the discrimination between levels being defined more by the scope of the consequences of an action rather than by the number of forces involved. During World War II, the beach landings on Okinawa and the ensuing battles were at the tactical level of war. Three months after the landings the island was secure and ready to be used as a launching point for strategic bombing of the Japanese homeland. This marked the achievement of a key operational objective of US forces in the Pacific Theater and the completion of the operational level Okinawa Campaign. The large number of casualties suffered by American forces during the Okinawa Campaign

shocked President Truman and significantly influenced his strategic level decision to drop the first atomic bomb on the Japanese homeland to hasten the end of the war.

ONTOLOGY

Guarino and Giaretta[6] noted that the term "ontology" had at least seven distinct meanings in the literature, and their work explained the implications of each interpretation for the knowledge engineering community. At the end of their paper, they suggested a set of definitions that is appropriate for this work. First, an ontology is a logical theory which gives an explicit, partial account of a conceptualization. Second, a conceptualization is an intentional semantic structure that encodes the implicit rules constraining the structure of a piece of reality. These two definitions give additional detail to Gruber's[7] early definition of ontology, which was "a specification of a conceptualization."

Ontologies are essential for developing and using knowledge-based systems. Every knowledge model has an ontological commitment[8], that is, a partial semantic account of the intended conceptualization of a logical theory. Thus the AI community has adopted ontology development as a prerequisite to building knowledge-based systems. The ontology captures that set of concepts used to describe the knowledge for the system.

Ontology development and use is an important area of research in AI[9]. Most research on ontologies focuses on what one might characterize as domain factual knowledge, but there is a segment of ontology research that seeks to represent, use and share knowledge about problem-solving methods, which is also important in knowledge-based system development[10].

Ontology research in the context of building knowledge-based systems has led to an organization of the knowledge base into an ontology and a set of problem solving methods[11]. The ontology provides a representation vocabulary with which to describe the facts and the concepts in a problem domain, meaning, the different kinds of objects in the problem domain, the properties of each object, and relationships existing between objects. These descriptions are also part of the ontology. The terms from the ontology are used to represent the problem solving methods (rules, cases, etc.) needed by the knowledge-based system to solve the problems for which it was designed.

The ontology is the more general component of the knowledge base, being characteristic of an entire domain, such as the medical, or military domains. A domain ontology specifies terms that are useful in a wide range of different applications in that domain. For instance, a military ontology would include specifications of military units and of military equipment that are very likely to be included in the knowledge base of any agent developed for a particular military

application. Moreover, there is generally wide agreement in any mature domain on the basic terms of that domain. This allows one to reuse ontological knowledge that was previously developed, in order to build a new knowledge base, rather than starting from scratch.

The problem solving methods represent the specific component of the knowledge base. They are not only specific to a particular application in a given domain, but they are even specific to a particular subject matter expert. Consider, for instance, a rule-based agent that assists a military commander in critiquing courses of action with respect to the principles of war and the tenets of army operations as described later in this paper. The rules will identify strengths and weaknesses in a military course of action, and will obviously be domain specific. Moreover, they are very likely to include subjective elements that are based on the experience of a specific military expert.

THE DISCIPLE APPROACH TO INTELLIGENT AGENTS

An intelligent agent is a knowledge-based system that perceives its environment; reasons to interpret perceptions, draw inferences, solve problems, determine and execute actions[12]. The agent's environment may be the physical world, a user via a graphical user interface, other agents, or other complex environments. Until recently, developing an intelligent software agent that assisted or replicated a Subject Matter Expert (SME), required the SME to work closely with a knowledge engineer who would actually build the agent[13]. The process of acquiring knowledge from an SME and representing it in the knowledge base of the agent has been found to be difficult and labor intensive, and is what has come to be known as the *knowledge acquisition bottleneck*. The process is slow and difficult because knowledge engineers and domain experts don't initially speak the same language. During this indirect knowledge transfer from the SME through the knowledge engineer into the agent's knowledge base, the SME and knowledge engineer must achieve a common understanding of the domain and how problems are solved in the domain. They must jointly produce a mutually understood representation of the domain and problem solving. There is, in a sense, a cross leveling of language and expertise. With today's intelligent learning agent tools, SMEs are getting closer to developing their own software products without the direct intervention of knowledge engineers.

The Learning Agents Laboratory (LALAB) at George Mason University (GMU) is developing an apprenticeship, multi-strategy, learning approach for building intelligent agents called Disciple. In the Disciple approach an SME teaches a learning agent how to perform domain-specific tasks in a manner that resembles the way the SME would teach a human apprentice, by giving the agent examples and explanations as well as by supervising and correcting the

agent's behavior[14]. Over the years, the LALAB has developed a series of increasingly more capable learning agents from the Disciple family, many of which address complex problems in the military domain. The general architecture of a Disciple agent is shown in Figure 1.

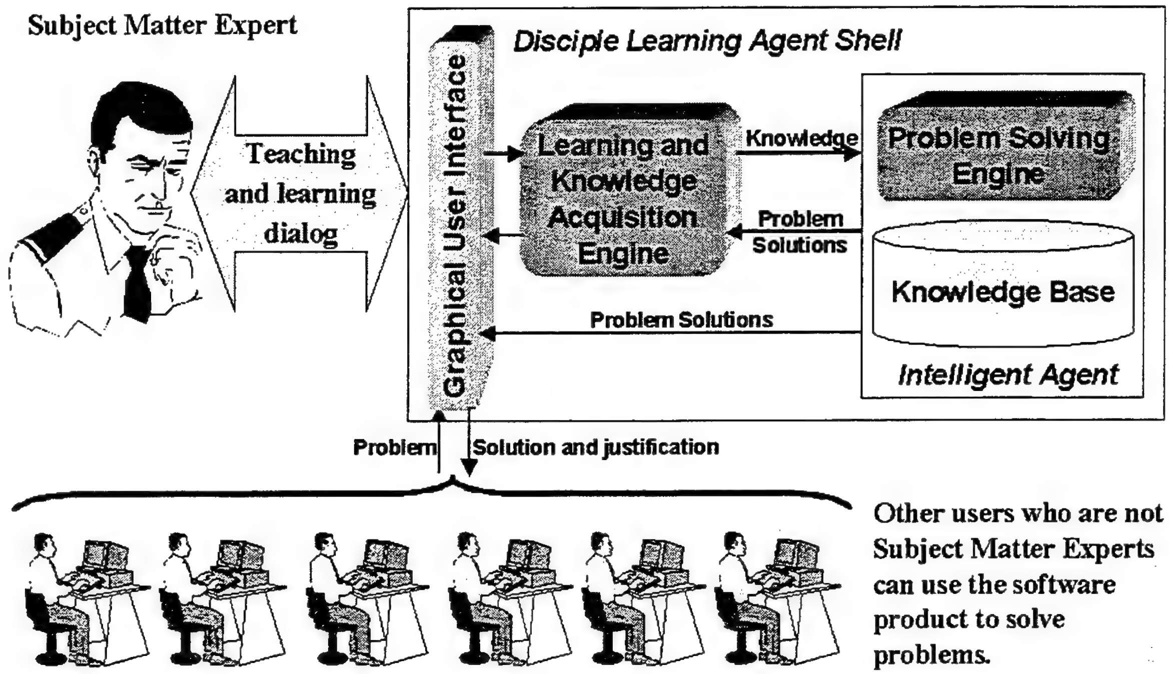

FIGURE 1. THE DISCIPLE ARCHITECTURE

The problem-solving engine is based on the task reduction paradigm of problem solving and is therefore applicable to a wide range of domains. In this paradigm, a problem to be solved is successively reduced to simpler problems until the problems are simple enough to be solved immediately. Their solutions are then successively combined to produce the solution to the initial problem. In order to acquire the knowledge of the SME, the learning and knowledge acquisition engine synergistically integrates several learning strategies, such as learning from examples, learning from explanations, and learning from analogy. The knowledge base is structured in two distinct components consisting of an object ontology and a set of reduction and composition rules. The object ontology is a hierarchical representation of the objects and types of objects for a particular domain. The object ontology provides a representation vocabulary that is used in the description of the reduction and composition rules. Each reduction rule is an IF-THEN structure that expresses the conditions under which a problem P_1 can be reduced to the simpler problems $P_{11}, \dots, P_{1n}$. Similarly, a composition rule is an IF-THEN structure that expresses the conditions under which the solutions $S_{11}, \dots, S_{1n}$ of the problems $P_{11}, \dots, P_{1n}$ can be combined into a solution S_1 of P_1. This structuring of the knowledge base is very important

because it clearly separates its most general part, the object ontology, from its most specific part, the rules.

An object ontology is characteristic of an entire domain. In the military domain, for instance, the object ontology will include descriptions of military units and of military equipment. These descriptions are most likely needed in almost any specific military application. Because building the object ontology is a very complex task, it makes sense to reuse these descriptions when developing a knowledge base for another military application, rather than starting from scratch. The rules from the knowledge base are much more specific than the object ontology. Consider, for instance, two agents in the military domain, one that critiques courses of action with respect to the principles of war, and another that plans the repair of damaged bridges or roads. While both agents will need background knowledge about military units and military equipment, their reasoning rules are very different, being specific not only to their particular application (critiquing versus planning), but also to the SMEs whose expertise they encode.

Under this agent-building paradigm, knowledge engineers support the SME's creation of a specialized Disciple agent rather than actually building the agent. They do this by customizing the graphical user interface, helping the SMEs learn how to teach the Disciple agent, and by facilitating the re-use of ontological knowledge found in established knowledge repositories such as the CYC knowledge base[15].

This paradigm eliminates much of the error generated by the many different people involved in the typical framework for software or agent development. Additionally, part of Disciple's output when it has solved a problem is an explanation of how it derived that solution. Thus other people who are not as familiar with the specific problem domain as the SME can use the trained version of Disciple to solve problems, understand the problem solving reasoning used, and learn themselves.

COURSE OF ACTION APPLICATION

Courses of action are outlines of plans for the manner in which a military force might attempt to accomplish a mission. Course of action development is done at each level of war. It is general military practice for a staff to generate several courses of action for a mission, and then make comparisons of those courses of action based on factors such as the principles of war and the tenets of military operations. After listening to the staff and receiving their recommendation, the commander of the combat unit makes the final decision as to which course of action to use for the mission. Course of action development at the tactical level of war is often done in haste. Both the staff's planning and the commander's decision making are

likely to be affected by combat stress, fatigue, hunger, and other environmental factors. Decision making can be decisive in combat and the United States military strives to select commanders based on proven ability to make good decisions under the most adverse conditions. Knowledge based systems, used as decision aids that are unaffected by environmental factors, could prove to be critical tools for military commanders and their staffs.

The goal of the HPKB research program was to produce the technology needed to rapidly construct large knowledge bases that provide comprehensive coverage of topics of interest, are reusable by multiple applications with diverse problem-solving strategies, and are maintainable in rapidly changing environments[16]. GMU researchers used the Disciple approach described above on the HPKB project. One of the DARPA HPKB challenge problems was to construct a critiquing agent that could evaluate military courses of action for ground combat operations, with respect to the principles of war and tenets of Army operations. To address the HPKB course of action challenge problem, the Disciple architecture in Figure 1 was extended[17] and used to develop the Disciple-COA agent.

Disciple's ontology includes objects, features, and tasks, all represented as frames, according to the knowledge model of the Open Knowledge Base Connectivity protocol[18]. The objects represent either individuals or sets of individuals. The objects are hierarchically organized according to the instance-of / type-of and subclass-of / superclass-of generality relationships. For Disciple-COA, an initial ontology was defined by importing the ontology built by Teknowledge and Cycorp for the courses of action challenge problem, which contained the vocabulary needed to represent courses of action. All HPKB participants working on the challenge problem shared it. A sample fragment of this ontology is shown in Figure 2.

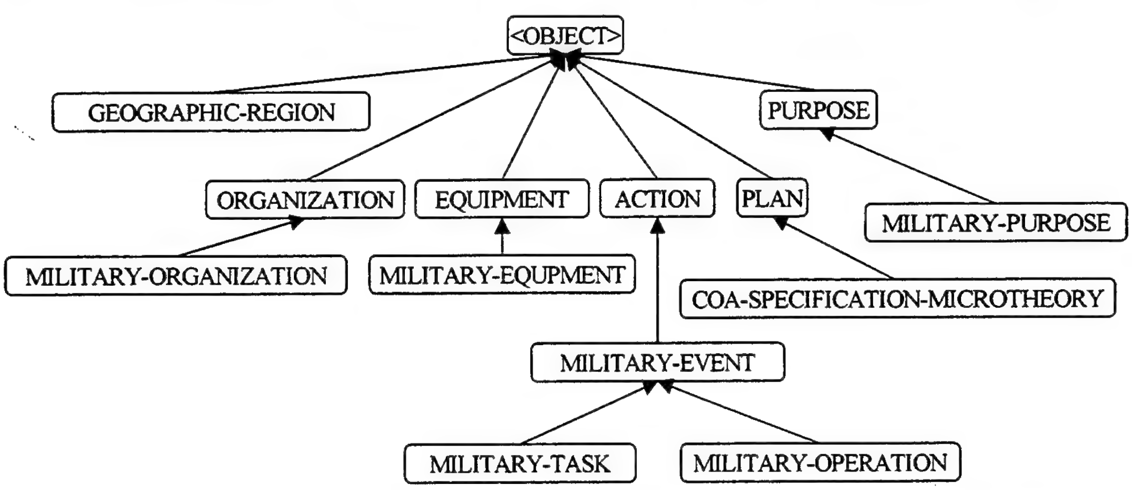

FIGURE 2. FRAGMENT OF TOP LEVEL ELEMENTS OF THE IMPORTED MILITARY DOMAIN ONTOLOGY

The imported ontology was refined and extended for the Disciple-COA agent using the ontology building tools of Disciple. Figure 3 shows that a high level element from Figure 2, MILITARY-TASK, has a substructure in which concepts and instances are described by specific values and features.

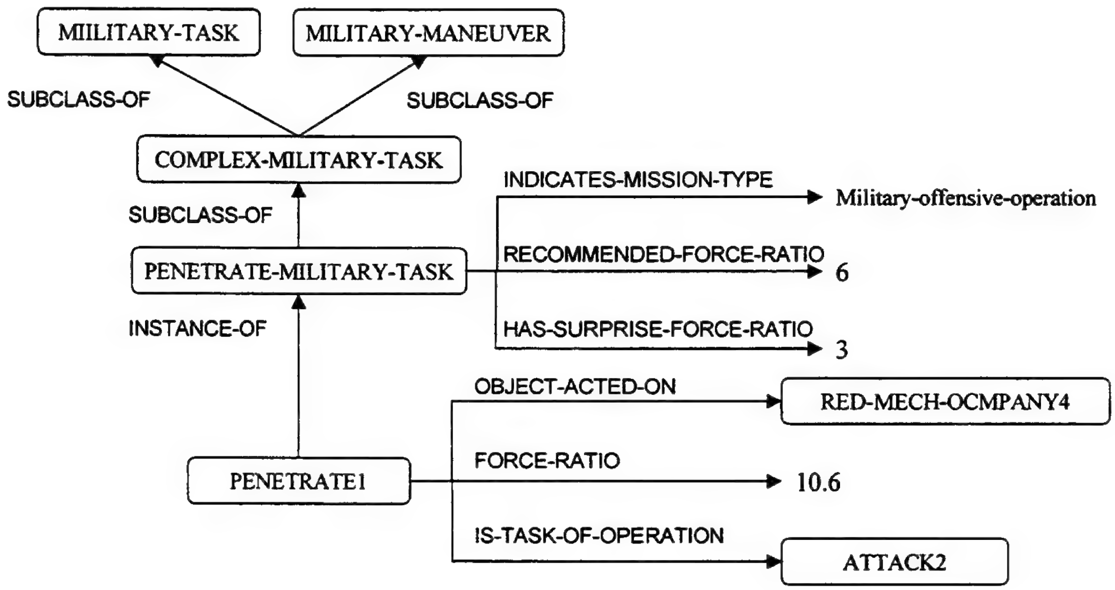

FIGURE 3. ADDITIONAL ONTOLOGY DEVELOPMENT USING DISCIPLE-COA

As part of the HPKB program, Disciple-COA and the other course of action critiquing agents were evaluated using five scenarios of increasing difficulty. The impressive results of this evaluation have been published.[19] In addition, GMU researchers conducted a one-week knowledge acquisition experiment using Disciple-COA at the U. S. Army Battle Command Battle Laboratory in Fort Leavenworth, Kansas[20]. This experiment took four military professionals experienced in both the tactical and operational levels of war but having no prior knowledge engineering experience and gave them approximately sixteen hours of training in AI and the use of Disciple-COA. Then starting with a knowledge base containing the complete ontology of objects and features in Disciple-COA but no rules, the military professionals were asked to train the agent to critique courses of action based on two principles of war – offensive and security. The agent training sessions lasted about three hours, and each expert, without measurable assistance from a knowledge engineer, successfully created an intelligent agent that correctly assessed COAs with respect to the principles of offensive and security.

Based on the HPKB evaluation results and those obtained at Fort Leavenworth, knowledge engineers in the USAWC Center for Strategic Leadership (CSL) proposed that the Disciple approach be used to address difficult military problems found at the operational and strategic

levels of war. This is being done with the cooperation and support of DARPA through its RKF program[21].

CENTER OF GRAVITY APPLICATION

One of the most difficult and often vexing problems that senior military leaders face at the strategic level of war is the determination and analysis of the center of gravity (COG) for friendly and opposing forces. Clausewitz introduced the concept of a center of gravity as "the hub of all power and movement, on which every thing depends.[22]" USAWC faculty members have debated the meaning of Clausewitz's words for many years. It is a controversial concept with several contentious issues. Each US military service (Army, Navy, Marines, and Air Force) has a different view of it, perhaps biased by their different perspective of the strategic and operational levels of war. To facilitate further study, CSL convened a working group of SMEs to attempt to give definition to the concept. These SMEs also worked with USAWC students (U. S. Army, U. S. Air Force, as well as International Fellows from the Egyptian, German, Philippine, Royal Thai, and Venezuelan militaries) interested in the problem. What emerged from this effort was published in a monograph with an accompanying process chart collectively entitled *Center of Gravity: Determination, Analysis, and Application*[23] (hereafter COG Monograph). Based upon this work, it is clear that the center of gravity concept can be applied at both the strategic and operational levels of war. At the strategic level of war, center of gravity determination is essential for maintaining focus on strategic goals, for allocating and using military resources, and for winning the war. Correctly identifying the strategic center of gravity is critical to the success of military campaigns at the operational level.

The ontology development for the center of gravity application builds on what was done for the course of action application. The course of action ontology provides an extremely important starting point, but the expansion of this ontology for center of gravity determination and analysis is extensive and complex because of the much greater coverage required for the new domain. Figure 4 presents "Step 1" of the COG Monograph. It has an immediate impact on any knowledge engineer having to do the ontology development for such a process. In just one category, "Economic Factors" for example, there are a plethora of objects, features, tasks and rules that can be added to the ontology used in Disciple-COA. This is to say that concepts such as MODERN-MILITARY-ORGANIZATION and MILITARY-TASK in the Disciple-COA ontology are still needed, but now it is likely that concepts such as GROSS-DOMESTIC-PRODUCT, DEPENDENCY-ON-IMPORTED-FOSSIL-FUEL, ELECTRIC-POWER-PRODUCTION, and more are also needed. The question is which of these concepts are needed in the majority of

scenarios that the agent will face and therefore should be part of an initial ontology. The human SME faces the same problem. Through experience and study, these experts have developed a framework of concepts that they quickly consider as they "Assemble Relevant Data."

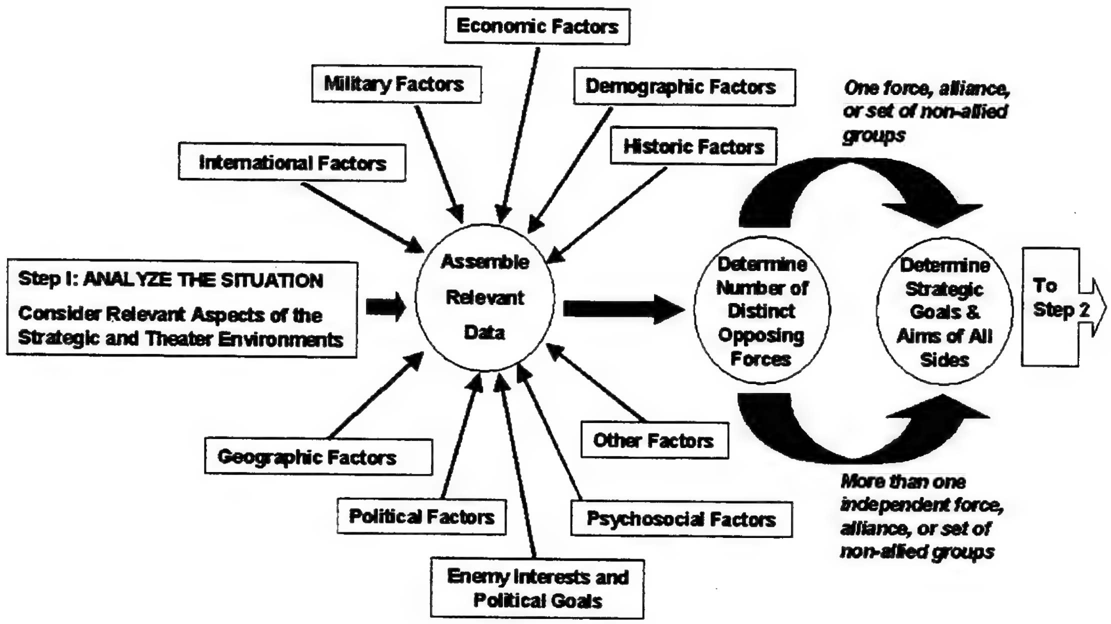

FIGURE 4. STEP 1 OF THE CENTER OF GRAVITY DETERMINATION PROCESS

USAWC faculty members continue to both study and teach center of gravity determination and analysis using the basic model provided by the COG Monograph. In an elective course devoted to the concept of center of gravity, students study military and crisis scenarios and do strategic and operational center of gravity determination for each opposing force in a selected scenario. Taking this same approach, knowledge engineers have begun the process of initial ontology development by studying two separate military campaigns, the World War II (WW II) invasions of Okinawa and Sicily. It is important to understand that instances of military actions very specific to the Okinawa Campaign, for example, are similar to instances in current day situations. These instances belong to concepts that must be captured in the basic ontological development if they are not found ready for import from ontology repositories such as CYC. For example, the motorboat Kamikaze attacks against US Naval vessels during the Okinawa Campaign are not unlike the modern-day motorboat terrorist attack recently directed against the USS Cole. A common element of both applications was the use of surprise, a principle of war understood by Disciple-COA. Yet another profound commonality between the two is found in religious beliefs, a "relevant" Psychosocial Factor, which must be introduced into the ontology.

For successful intelligent agent development using the Disciple approach two key elements are necessary. The first is a selection of scenario data files from the appropriate problem domain. These data files serve as the external environment that the agent senses and to which it responds. The second necessary element is a source of domain expert problem solving knowledge. The Disciple methodology appears to be ideally suited for use in this domain and the USAWC environment. Disciple provides a wide range of flexible tools for ontology, knowledge base and agent development and the USAWC has the necessary domain expertise and scenarios. Consequently, CSL knowledge engineers will work with USAWC students taking the elective course entitled "Case Studies in Center of Gravity Determination" during the spring 2001 term. Each student in this class is required to select a historical campaign or contemporary planning scenario and do strategic and operational center of gravity determination for each of the opposing forces. They will use a newly developed feature of Disciple that will allow them to describe the selected scenario in a natural user-Disciple dialog. Based on this dialog, Disciple will extend and populate a generic ontology for center of gravity determination and analysis. The ontologies developed in this way will be used by the USAWC students in a subsequent elective course entitled "Military Applications of Artificial Intelligence" to further develop and train Disciple-COG agents.

The USAWC is fortunate to have among its faculty several members of the original working group that produced the COG Monograph. These subject matter experts will be asked to evaluate the results produced by Disciple-COG.

LESSONS AND ONTOLOGY CONSIDERATIONS LEARNED

During the fall of 2000 and spring of 2001 an intensive effort was made to extend the Disciple-COA ontology for use as the Disciple-COG ontology. The WWII Okinawa and Sicily campaigns served as the initial examples. The developed ontology is documented in a set of diagrams (over 100 pages in length) that represents the concepts and relationships expressed in the COG Monograph with instances of those concepts and relationships evident in the Okinawa and Sicily campaigns. This ontology will also be represented in the knowledge base data files used by the initial Disciple-COG agents and then extended by and for other scenarios developed by USAWC faculty and students. In the course of this effort numerous, potentially important extensions were made to the concepts and relationships laid out in the COG Monograph suggesting that it may be time to revise and republish this work.

OPPOSING FORCES

A primary lesson learned is that a key first step in successfully conducting center of gravity determination and analysis as described in the COG Monograph is the correct selection of the opposing forces to be analyzed. This must be followed by a detailed identification of the opposing force's composition, characteristics, and nature. Is the opposing force a coalition or alliance of nation states or an individual nation state? Is it an ad hoc group of clans or a single terrorist organization? Figure 5 is a sample of the high level concepts and relationships necessary for correctly representing opposing forces and some historical instances of such forces.

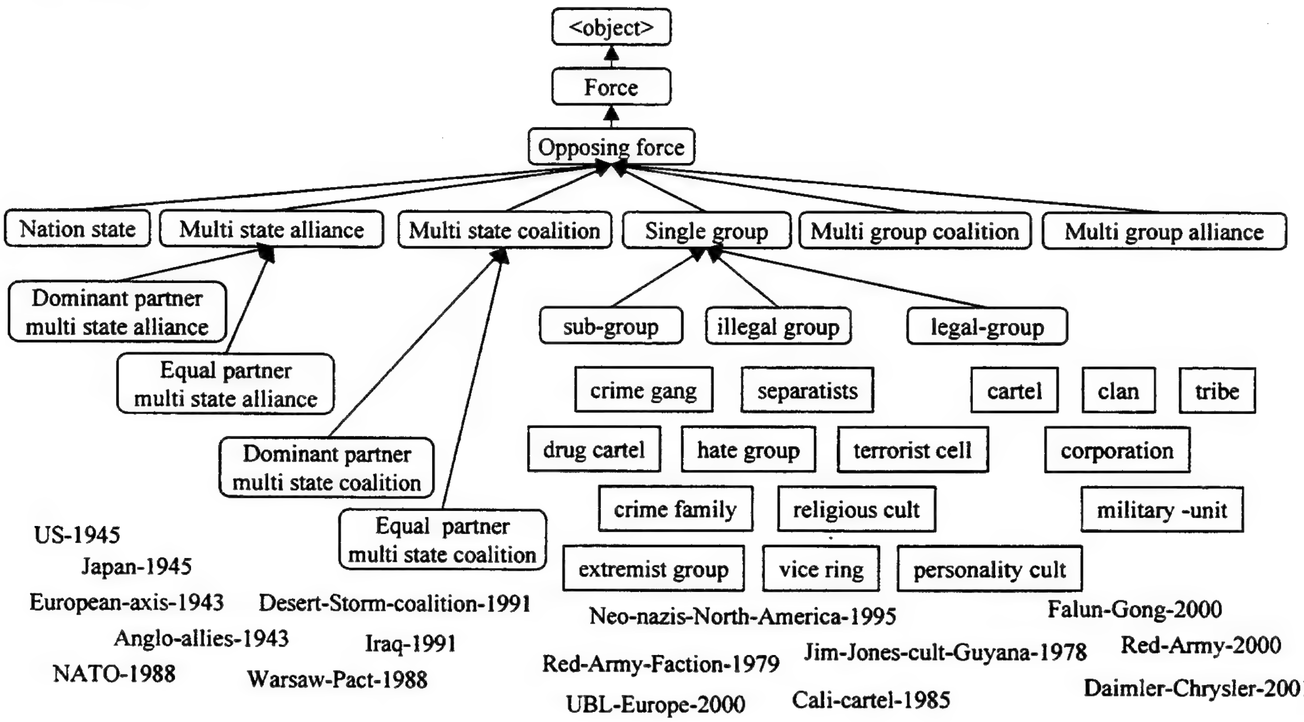

FIGURE 5. CENTER OF GRAVITY HIGH LEVEL ONTOLOGY

The Okinawa and Sicily campaigns clearly demonstrate the complexity of the first step. These WWII scenarios addressed campaigns in the same global conflict but occurred roughly two years apart and with significantly different environments and circumstances. The Sicily campaign followed quickly after successful allied operations in North Africa. At the time, the US and Britain were equal partners in the alliance with roughly equal numbers of troops available for the operation. On the axis side, Germany was the dominant member of the Italian-German alliance, but the majority of the axis troops involved in the operation were Italian. Our conclusion was that the proper representation of the US-British forces for this scenario is as shown in Figure 6, concentrating on the composition, characteristics and nature of the two,

multi-nation state alliances. For Okinawa on the other hand, our conclusion was that even though the US was still part of a functioning US-Britain-Soviet alliance, it was more appropriate to concentrate on just the US as a single nation state opposing force on one side and Japan on the other. As an example of a third case, it would seem appropriate to consider the United Nations supported multi-nation state coalition as one opposing force in the 1991 Gulf War and Iraq, a single nation state, as the other. Scenarios involving non-nation states such as clans, tribes, terrorist organizations, drug cartels, corporations, and other complex transnational groups will require additional ontology development but can be represented within the framework we have developed as shown in Figure 5 above.

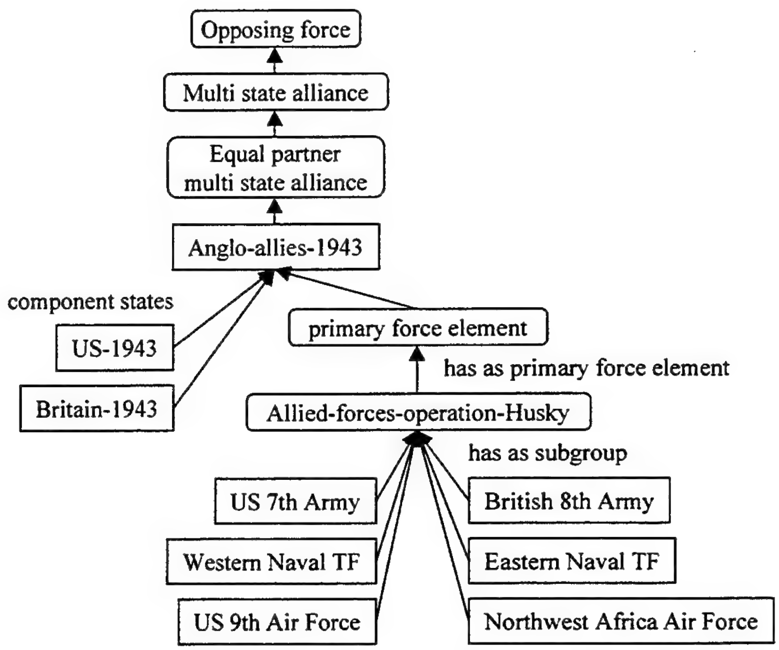

FIGURE 6. ORGANIZATION OF THE ALLIES FOR THE SICILY CAMPAIGN

RELEVANT FACTORS

Our work with relevant factors does not suggest a need for new categories of factors. It does suggest that it is important and useful to break down the category of "Enemy Interests and Political Goals" into two subcategories: "strategic interests and goals," and "operational interests and goals."

The more interesting and challenging lesson learned in this area is that each of the categories of relevant factors must be considered not only for each opposing force, but ultimately for each sub-group of each opposing force. This issue is directly related to the selection of opposing forces as described above. Some number of relevant factors will be of

primary importance and applicability for an opposing force and others will be more applicable to its sub-groups. If it becomes apparent that a large majority of relevant factors that the analyst feels should be considered for an opposing force are actually more applicable to the sub-groups of that force, then it is possible that the wrong opposing force is being used. This was the case with the Okinawa scenario. The US-Britain-Soviet alliance was still in existence in 1945 and a small number of British naval units were involved in the campaign. Examination of the relevant factors that appeared to be important for this opposing force all pointed to the US and made it quickly apparent that the US-1945 and not the US-Britain or US-Britain-Soviet alliances, was the proper opposing force to consider for this scenario.

Clearly, it appears that in any scenario that involves a multi-state or multi-group alliance or coalition, the ontology and knowledge base must allow for the representation and categorization of relevant factors for each group of entities as well as each individual entity involved in the scenario.

COMPOSITION OF FORCES

The identification and representation of the composition of forces involved in a scenario is relatively straightforward if the opposing forces have been properly identified. The categories of "single entity opposing force", "alliance" and "coalition" appear to be adequate for describing the composition of an opposing force. The COG Monograph steps its way to definitive conclusions that the "Will of an Equal Partner Alliance or Coalition" is an appropriate candidate strategic COG for an opposing force of that composition. It appears to reach the conclusion just as definitively that the "Will of the Dominant Alliance or Coalition Member" is an appropriate candidate COG for an opposing force comprised of a "dominant partner alliance or coalition." These conclusions are intuitive and are supported by some historical examples, but there is very little supporting explanation for them in the COG Monograph.

Based on our analysis of current US joint doctrine and practice we propose an addition to the Composition of Forces section of the COG Monograph. Given the complexity of modern combined and joint operations, in cases where an alliance or coalition is conducting "combined," or "combined and joint" operations we propose that an additional, valid candidate strategic COG would be "Cooperation between alliance or coalition members." Additionally, we propose that in scenarios where the primary force element of an opposing force is conducting "combined," "combined and joint," or "joint" operations, an additional, valid candidate operational COG would be "Cooperation between sub-groups of the primary force element."

CONTROLLING ELEMENTS AND GOVERNING BODIES

By far the most difficult challenge that we encountered in developing an ontology to support center of gravity determination and analysis as it is described in the COG Monograph was with the closely related areas of "Primary Controlling Element(s)," and "Type of Government" as shown in Figure 7. We concluded that these sections of the COG Monograph are either redundant or incompletely developed. The names, "Primary Controlling Element(s)," and "Type of Government," have obvious close relationships. The COG Monograph suggests the conclusion that a leader or governing body can be a candidate strategic COG in both of these categories for scenarios where a "governing body" is determined to be the "primary controlling element" for an opposing force or sub-group. While this is an intuitive conclusion, in those scenarios where two different entities appear to be important, such as a leader and a political party, the COG Monograph offered very little documentation to support which categorization is appropriate in each case.

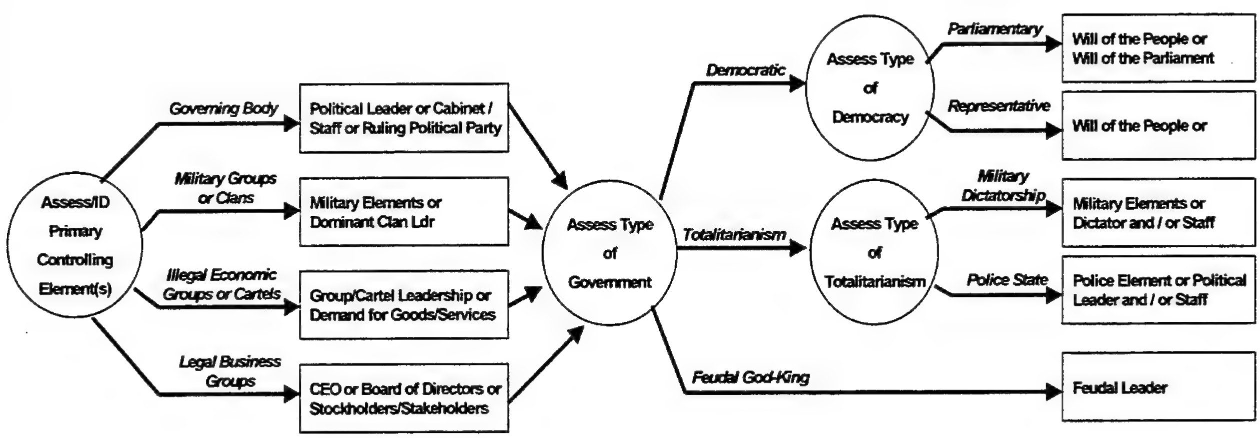

FIGURE 7. GOVERNMENT TYPE AND CONTROLLING ELEMENTS DIAGRAM

One conclusion we reached for this area of the COG Monograph was that in the case where a coalition or alliance is the opposing force, these two elements will not always be applicable. Long-term, formal alliances like the North Atlantic Treaty Organization (NATO) may have a governing body and/or a primary controlling element that should be considered as a candidate strategic COG. Short term or ad hoc alliances or coalitions may not have a governing body or person that fits these categories. NATO's governing body had direct control over NATO actions in Kosovo in 1999 and would appropriately be considered a candidate COG. Desert Storm Coalition forces, on the other hand, had no single governing body or primary controlling element. A US commander controlled forces supplied by the US and NATO, while a Saudi commander controlled forces from Arab nations. It appears to be more appropriate in this case

to look at the governing bodies and primary controlling elements of the US and Saudi Arabia, lead nations of the coalition, for candidate strategic COGs.

What we clearly determined was that it is of critical importance that the ontology and knowledge base allow for the identification of two or more closely related decision making individuals or groups, as candidate strategic COGs, in these related categories. We war-gamed numerous examples for scenarios suggesting that regardless of the nature of the opposing force (nation state or group), that force would have some type of governing body. That governing body will have a decision-making methodology such as voting in a democratic governing body, or a single autocratic authority figure in the case of a dictatorship. In addition to these key decision makers of the governing bodies, it will be common for there to be a second, potentially equally important "primary controlling element" in the opposing force. The distinction between these two elements remains cloudy, but situations where two or more closely related candidate strategic COGs are appropriate are easy to identify. As shown in Figure 8, examples include:

Scenario	Type of Government Candidate Strategic COG	Primary Controlling Element Candidate Strategic COG
US 1943	Will of the People	President Roosevelt
Germany 1943	Nazi Party	Adolph Hitler
Italy 1943	King Emannual III	Benito Mussolini
Japan 1945	Emporer Hirohito	Japanese Imperial Staff

FIGURE 8. EXAMPLE COGs FOR GOVERNMENT TYPE AND CONTROLLING ELEMENTS

A final recommendation that we have for the "Primary Controlling Element(s)" and "Governing Body" elements of the COG Monograph is that they be extended to cover religion focused nation states and groups. Additional analysis and coverage for illegal and legal transnational organizations is also needed. With their increased numbers and their potential asymmetric security threats to the United States, inclusion of these non-traditional states and organizations in the center of gravity determination and analysis process will be critical.

Figure 9 shows the ontology development with respect to governing bodies and government types completed to cover the scenarios selected for use in the spring of 2001.

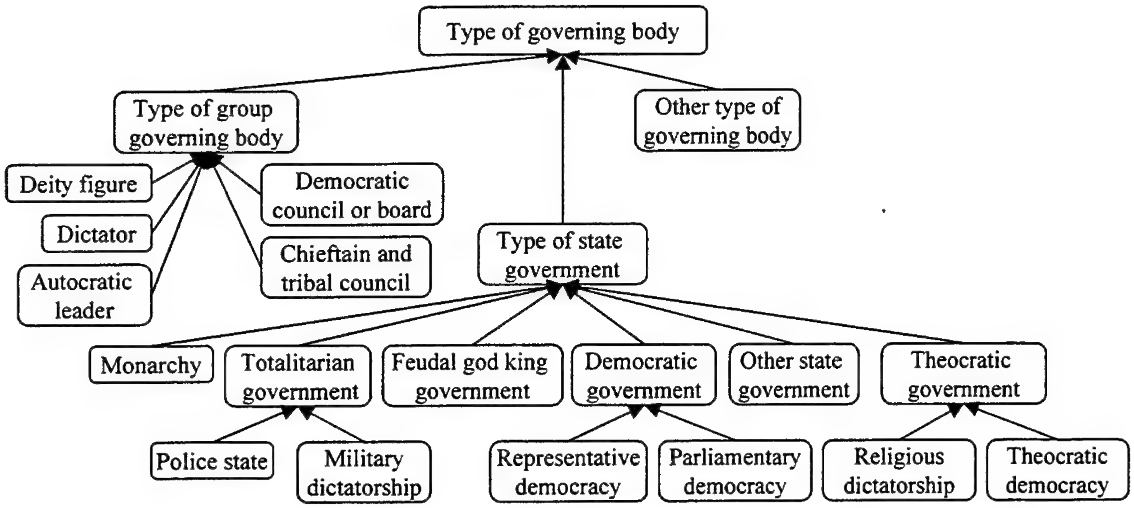

FIGURE 9. GOVERNMENT AND GOVERNING BODY TYPES

CIVILIZATION

Our work with the aspects of civilization type and strategic COGs does not suggest the need for additional categories of civilization type. What is strongly suggested is the need for much finer resolution in the list of candidate strategic COGs for industrial and informational level civilizations. The COG Monograph is incomplete in its elicitation of these candidate strategic COGs. In the category of "industrial civilization" the COG Monograph lists only "Commerce Authority" and "Industry Authority" as candidate strategic COGs. We proposed that this list be expanded to at least those listed in Figure 10. The identification of potential candidate COGs for an Informational Civilization is certainly incomplete. A detailed analysis to identify potential COGs for an information based civilization and operational forces is necessary and is probably an excellent subject for a future USAWC Strategy Research Project.

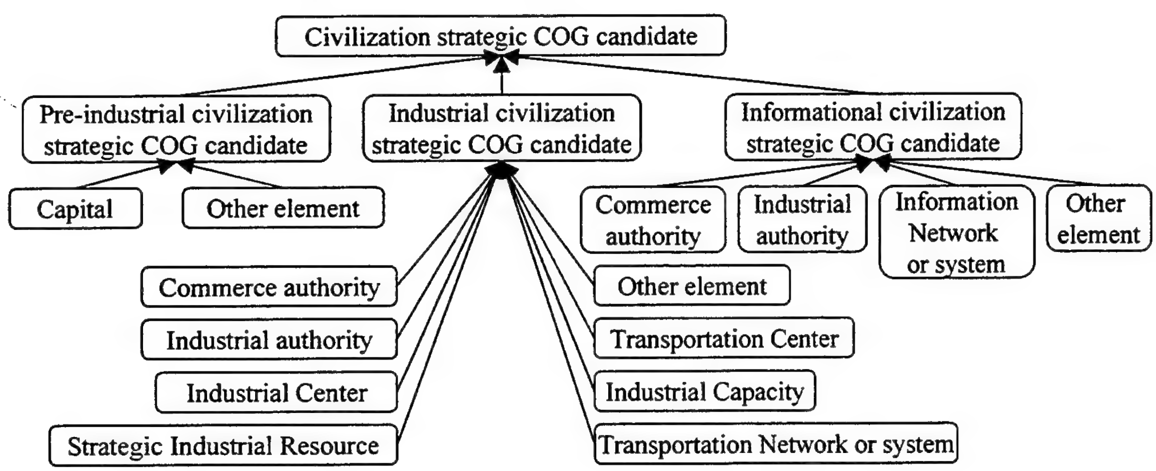

FIGURE 10. CIVILIZATION BASED CANDIDATE CENTERS OF GRAVITY

CONCLUSION

Ontology development is critical to the creation of successful knowledge-based systems. The military has numerous problem domains at the tactical, operational, and strategic levels of war where knowledge-based systems have been and can be deployed. DARPA and the US Air Force Office of Scientific Research, through the HPKB program supported the development of a tactical course of action critiquing intelligent agent, called Disciple-COA, by researchers at George Mason University. All participants in the HPKB program shared an initial military ontology developed by Teknowledge and Cycorp. The built-in ontology tools found in the Disciple system enabled further ontology development. The evaluation results for Disciple-COA were impressive and caused knowledge engineers at USAWC to recommend that Disciple be focused on the strategic level problem of center of gravity determination and analysis for DARPA's RKF program. George Mason University researchers agreed with this recommendation. DARPA subsequently approved it, and ontology development for Disciple-COG is underway. This paper described the ontology development and extensions to the USAWC center of gravity determination and analysis process that have been completed to date as a result of this research, and proposed directions for future efforts.

WORD COUNT = 5980

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